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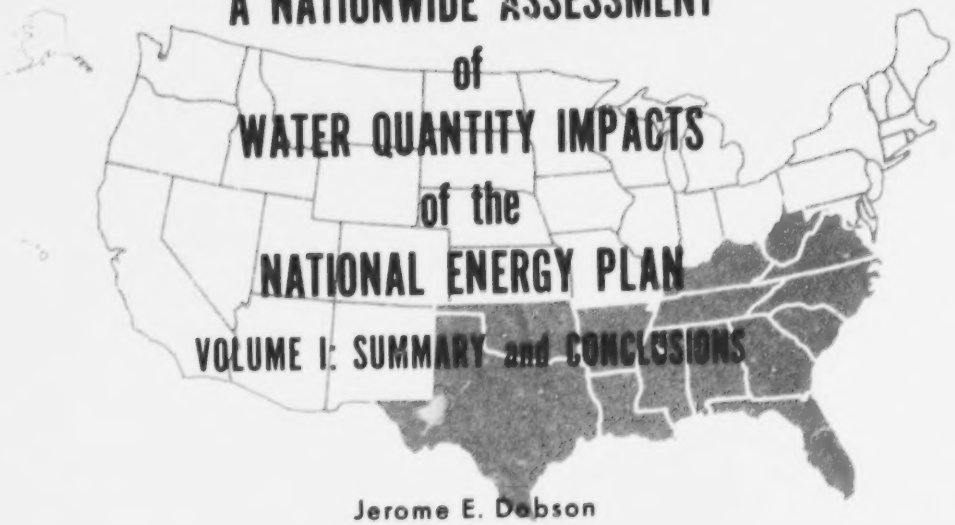
A NATIONWIDE ASSESSMENT of WATER QUANTITY IMPACTS of the NATIONAL ENERGY PLAN

VOLUME I: SUMMARY and CONCLUSIONS



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ORNL REGIONAL STUDIES PROGRAM

OAK RIDGE NATIONAL LABORATORY
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ENERGY DIVISION

A NATIONWIDE ASSESSMENT OF WATER QUANTITY IMPACTS OF THE NATIONAL ENERGY PLAN VOLUME I: SUMMARY AND CONCLUSIONS*

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ABSTRACT

The water requirements of steam electric generating plants, coal liquefaction and gasification facilities, and coal extraction activities projected for 1985 are calculated, and impacts associated with the National Energy Plan (NEP) Initiative are compared with those of a Base Case Scenario for the conterminous United States. It can be concluded that there is no appreciable difference in water quantity impacts at the Water Resources Council Aggregated Subarea (ASA)* level. Consumption as a percentage of the surface supply never varies by more than one percent between the two scenarios except for the Trinity Basin of Texas, and most of the differences are reductions from the Base Case to the NEP.** However, for either case there will be a considerable increase in water use for energy between 1975 and 1985, and water availability may constrain development in several basins of the western United States. Even in the humid eastern United States localized water problems may occur on certain small tributaries.

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*ASAs are clusters of counties approximating tributary river basins, and portions of main stem basins, and groups of small river basins.

**For the Trinity River Basin water consumption under the NEP scenario is 3.8% less than for the Base Case.

EXECUTIVE SUMMARY

This report examines the water quantity impacts which may be anticipated as a result of the National Energy Plan (NEP). The water requirements of steam electric generating plants, coal liquefaction and gasification facilities, and coal extraction activities projected for 1985 are compared to water availability for energy, and impacts associated with the NEP Initiative are compared with those of the Base Case for the conterminous United States. The Base Case assumes that current trends in energy production and consumption are not subjected to any major policy change whereas the proposed plan, if enacted, would accelerate the current shift from oil- and gas-fired generating facilities to coal-fired and nuclear generating facilities. The concern over future water requirements for energy stems from the growing dependence on electricity relative to other fuels and on steam electric generation relative to other, less water consumptive, forms of generation. Relative to the Base Case, the NEP affects these trends by reducing total electricity demand and encouraging redistribution of energy facilities between and within regions. This analysis is intended to determine the effect of these shifts on water requirements for the energy sector.

Analysis of the projected water quantity impacts of energy production focuses on the seasonal period when the total water demand utilizes the greatest proportion of estimated supply. The nationwide analysis was conducted at the Water Resources Council Aggregated Subarea (ASA)* level. Surface water supply estimates are based on the 95% exceedence level (the ASA surface outflow with a 95% chance of being exceeded) in each basin's critical supply month. Problem areas are defined wherever consumptive use constitutes a large percentage of this estimated supply.

The study is limited to 1985 and, therefore, cannot be expected to detect major water supply problems in the Eastern United States. Previous Base Case studies have shown water shortages in the East only on certain tributaries by 1985 with some main stem shortages developing by 2000.

The ASA projections for 1985 should be regarded as conservative estimates of any problems that may be identified. The comparison of aggregate basin consumption against streamflow at the point or points of exit from the basin could mask additional problems that may exist where a disproportionate amount of the consumption occurs on a small tributary or on a small stream flowing directly to the sea. Using average rates of consumption rather than instantaneous peak consumption also tends to mask potential shortages. Furthermore, the 95% exceedence level used in this report tends to be higher than other measures of streamflow,

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*ASAs are clusters of counties approximating tributary river basins, portions of main stem basins, and groups of small river basins.

such as the 7-day/10-year low flow,* which are preferred by many water resources specialists and which have legal standing in some states.

For the nation as a whole it can be concluded that there is no appreciable difference in water quantity impacts at the ASA level between the Base Case and NEP Initiative. Statistically the two distributions are almost identical (r = .97), and a basin-by-basin comparison shows that in most ASAs there is no difference in consumption as a percentage of the surface supply. This percentage, indicating the magnitude of water resource impacts, never varies by more than one percent except in the Trinity River Basin of Texas (Figs. 1 and 2). Significantly, most of the differences are reductions attributable to the NEP. This finding, however, should not be interpreted as an optimistic prediction that water quantity impacts will be negligible in 1985. There will be a considerable increase in water use for energy between 1975 and 1985, and water availability may constrain development in certain basins (Fig. 3).

Subregional studies that are focused on smaller tributary basins and that use more restrictive measures of water availability have been performed in the Ohio, Upper Mississippi, and Missouri River Basins and in FEA Region VI (Arkansas, Louisiana, New Mexico, Texas, and Oklahoma). The 7-day/10-year low flow has been calculated for each subregion, and 10% of this figure has been assumed to be available for energy purposes. Rates of water consumption are for steam electric generation only.

In the Ohio River Basin the NEP Initiative will have no greater impact on water use by the energy sector than the Base Case, but in either scenario there will be negative impacts on the water supply of the region. The Ohio River Basin contains one of the major concentrations of economic activity in the nation and is the area most likely to experience significant impacts of future growth based on coal reserves. Applying the Ohio River Basin Commission's guideline that 10% of the 7-day/10-year low flow is a critical level for water consumption by the energy sector, only the Big Sandy-Guyandotte region would be identified as a problem area in 1985; the Monongahela would consume the next highest percentage of the low flow. This comparison, however, represents average consumption by all plants in the region. If all of the base-load plants on a given tributary were running at or near maximum capacity during the low-flow period, consumption would also equal or exceed 10% on the Monongahela, Green, and Allegheny Rivers. It is significant that in a basin the size of the Ohio, situated in the "water rich" eastern United States, some tributaries may experience water supply problems in meeting energy requirements at low flow. This suggests the beginning of a water supply problem that may constrain energy development after 1985.

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*The 7-day/10-year low flow estimates are not available for the entire nation; the 95% exceedence level was used except for subregional studies in the Ohio, Upper Mississippi, and Missouri River Basins and FEA Region VI.

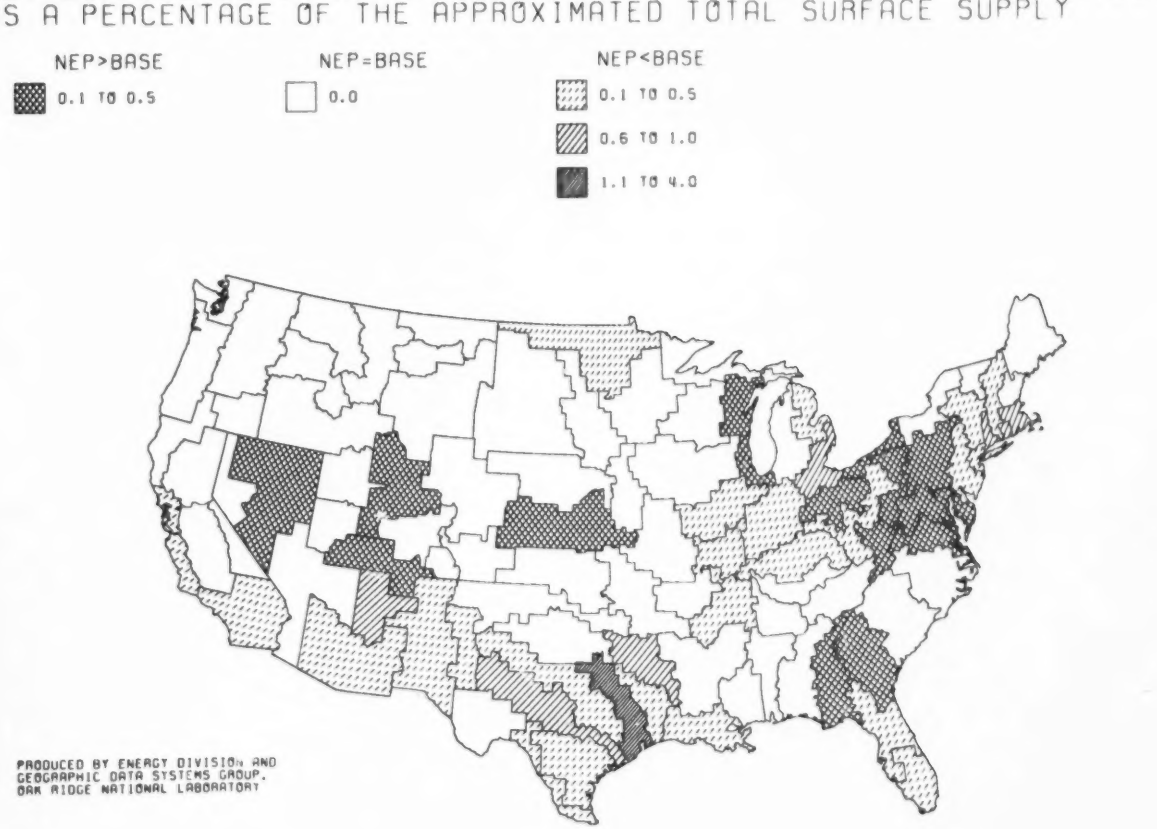

Fig. 1. The water resource impacts of the NEP are almost identical to the 1985 Base Case. Water consumption by all energy facilities as a percentage of the surface supply varies by less than 1% (of the supply) in every ASA except the Trinity River Basin in Texas.

WATER RESOURCES COUNCIL AGGREGATED SUBAREAS

Fig. 2. Water Resources Council Aggregated Subareas (ASAs) are shown by reference number for the conterminous United States. The first digit of each three-digit number and the first two digits of each four-digit number indicate the WRC region number.

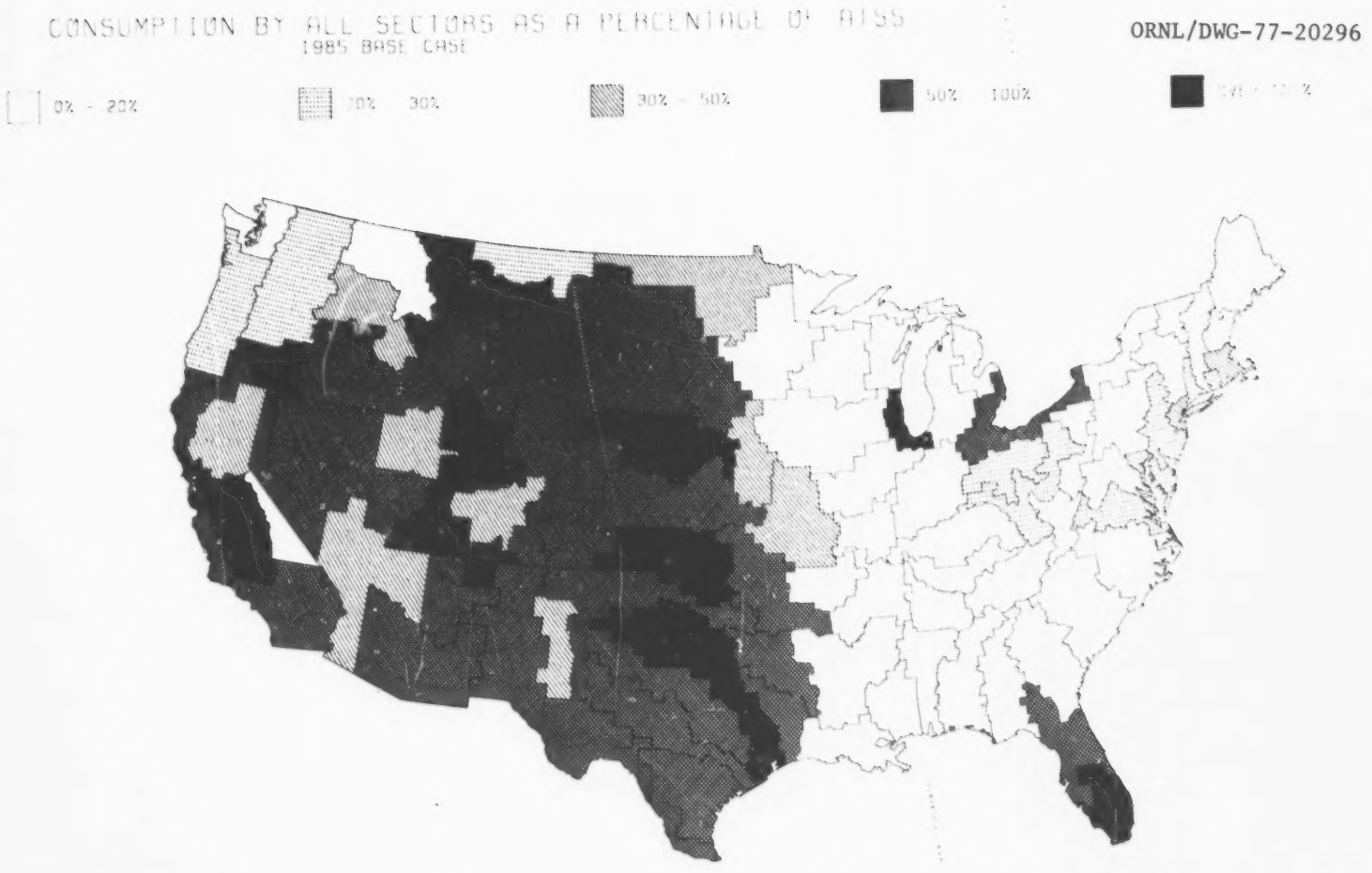

Fig. 3. Water consumption by all sectors constitutes a significant percentage of the Approximated Total Surface Supply (ATSS) in most basins of the West and in a few basins of the East. Percentages in basins adjacent to the Great Lakes are misleading because lake waters are not included in the estimate of surface supply.

By the year 1985, no major supply problems were detected at the ASA and subregional levels in the Upper Mississippi River Basin for energy facilities, based on both the NEP and Base Case scenarios. However, due to increasing demand and limited resources, water supply problems are expected in some localized areas. Water problems could occur for energy development on the Illinois River, the Minnesota River, and the Cedar River where generation units may be sited subject to seasonal or periodic low flows. Depending on the specific sites, it may be necessary to provide reservoirs or short-term storage facilities to maintain water supplies for generation in these areas during critical conditions.

Based solely upon the available water from streams and consumptive water requirements for electric generation, surface water supply could be a problem in several subregions of the Missouri River Basin in either scenario. It is estimated that steam electric facilities will consume more than 100% of the 7-day/10-year low flow of the Powder and the North and South Platte Rivers, about 95% of the flow of the Platte River, 50% of the Smoky Hill and Grand Rivers, 25% of the Cheyenne River, and 25% in southeastern South Dakota. In these areas, if water demands are to be met for either scenario, augmentation from reservoirs or groundwater and/or use of less water-consumptive technologies will have to be the rule.

In FEA Region VI the NEP causes no impact significantly different from that of the Base Case in any subregion. However, even with average rates of consumption by energy facilities, water problems are apparent at low flow in the Arkansas-Keystone, the North Canadian, the Neosho-Verdigris, the Sabine, the Trinity, the Middle and Lower Brazos, the Lower Pecos, the Rio Grande-Amistad, the Rio Grande-Falcon, and Lower Rio Grande Rivers and in the Galveston Bay-San Jacinto, Lower Colorado-Bernard-Coastal, Central Texas Coastal, and Nueces-Southwestern Texas Coastal Basins. The NEP Initiative tends to alleviate some of the problems anticipated with the Base Case, but in no instance is the reduction in water demand great enough to cause a problem subregion to meet the 10% of the 7-day/10-year low-flow guideline. In the more restrictive calculation in which all base-load plants on each tributary are assumed to be operating at or near maximum capacity during the low-flow period, the White River and the Louisiana Coastal Subareas also are defined as problem areas in the Base Case but not in the NEP Initiative scenario.

It is clear that the NEP will have little impact on water availability relative to the Base Case in 1985, but major effects, positive or negative, could not have been expected so soon. The projection date of 1985 is only eight years away, and the lead time for constructing most new energy facilities is four to eight years or longer. This suggests that, if any significant changes in water use do occur, they will be apparent only after 1985. An analysis of the water resource impacts in 2000 would provide a much clearer understanding of the long-range impacts associated with the NEP.

It should be recognized that the water requirements of other sectors may also be affected by the NEP. Redistribution of population and industrial activity, for example, may result from the shift to coal and electricity, and boom towns in certain coal mining regions may require more water than the mining activity itself. Likewise secondary industrial growth and related urban growth may require considerable amounts of water. The significance of these impacts should be examined in a study of broader scope than this analysis.

A Nationwide Assessment of Water Quantity Impacts
of the National Energy Plan
Volume I: Summary and Conclusions

1. Introduction

This report examines the water quantity impacts that may be anticipated as a result of the National Energy Plan (NEP).[1] The water requirements of all electric generating plants, coal conversion facilities,* and coal extraction activities projected for 1985 are calculated, and their impacts are compared between the NEP Initiative and the Base Case for the conterminous United States. Special studies have been conducted at greater detail in the Ohio, Upper Mississippi, and Missouri River Basins and in the south central United States (Fig. 1.1). This report focuses on water quantity as opposed to water quality, which is being covered in a related study by Argonne National Laboratory (ANL).** Both ANL and Los Alamos Scientific Laboratory contributed to this water quantity analysis.

The Base Case assumes that recent trends will continue to 1985 and that the development plans announced by utility companies are essentially correct. Utilities throughout the nation have shown a preference to shift from oil- and gas-fired generating facilities to coal-fired and nuclear generating facilities in their new construction and planning. The proposed NEP, if enacted, would accelerate this trend through its incentives to retire existing oil- and gas-fired plants or to switch to alternative fuels wherever retrofitting is possible.

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*The term "coal conversion facilities" refers to coal liquefaction and gasification plants.

**A draft report on water quality impacts of the NEP is in review and soon will published as an Argonne National Laboratory report.

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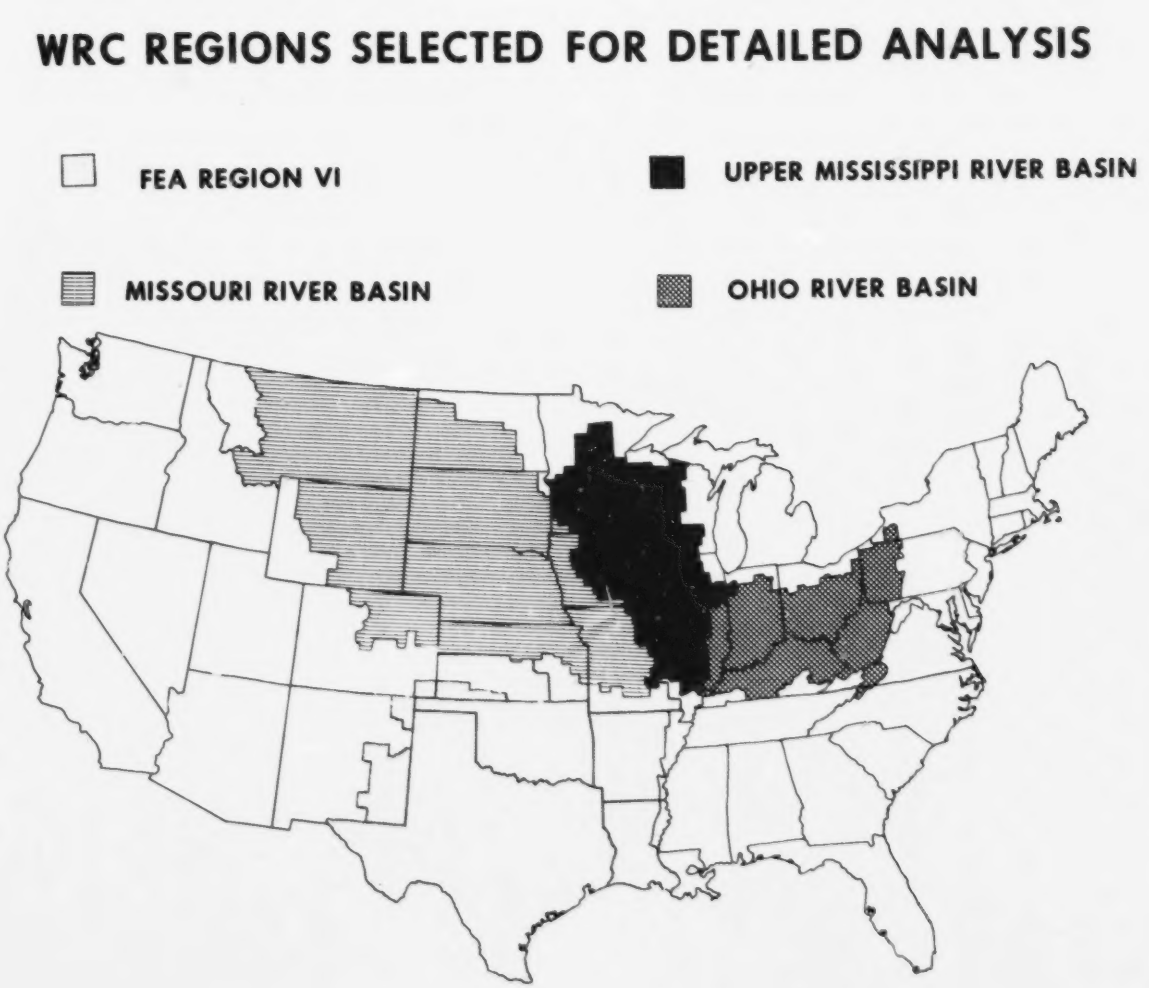

Fig. 1.1. Regions selected for detailed analysis.

Some locational redistribution of generating plants can be anticipated from the NEP due to the different siting requirements of various technologies. For example, gas-fired plants currently can be located in urban areas where nuclear plants are excluded because of population restrictions and coal-fired plants often are unacceptable due to air quality maintenance standards. Similarly, increased utilization of coal may cause greater concentration of generating facilities in coal supply regions even though the national aggregate electricity demand is intended to be somewhat lower under the NEP.

1.1 Purpose and Scope

The purpose of this analysis is to identify and compare significant water resource impacts that may result from the Base Case and NEP Initiative and to indicate the magnitude of the differences in water use under these two scenarios by 1985. In both scenarios, problem areas are defined wherever the water requirements for energy facilities are projected to exceed the amount estimated to be reasonably available.

1.2 The Effects of the NEP on Water Requirements

Currently the water requirements for steam electric energy facilities comprise a major portion of total withdrawal and a smaller portion of total consumption in most river basins of the eastern United States,* reaching 74% of withdrawal and 18% of consumption on the Tennessee River. In the western United States these percentages are much lower, due to the large requirements of irrigation and the lower electricity

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*"Withdrawal" refers to the entire volume of water required for circulation through a facility or process whereas "consumption" refers only to the portion that is consumed and is not available for further use (e.g., evaporative loss).

demand, but water shortages are already apparent. In many areas any new use must come at the expense of traditional uses and will offer the alternatives of decreased productivity or more efficient use of water supplies. In both areas, the concern over future water requirements for energy stems from the growing dependence on electricity relative to other fuels and on steam electric generation relative to other, less water consumptive, forms of generation. The NEP would affect these trends in the following ways:

1. The NEP reduces total energy demand so that electricity demand is slightly lower for the NEP Initiative as opposed to the Base Case. If all other factors were held constant, this would cause NEP water requirements to be slightly lower than those of the Base Case for the nation as a whole.

2. Changes in fuel type are primarily shifts from oil and gas steam electric to coal and nuclear steam electric or from gas combustion turbine to oil combustion turbine. Dependence on steam electric generation is virtually unaffected by the NEP. Oil-, gas-, and coal-fired plants of the same efficiencies and cooling modes are almost identical in their water use, whereas nuclear plants require considerably more cooling water. If a significant portion of the replacement capacity in any ASA were nuclear, the result would be a significant increase in water withdrawal and consumption over the Base Case. In addition, the Best Available Control Technology (BACT) provisions of the Clean Air Act will require scrubbers to reduce sulfur oxides emissions (SO_2) from coal-fired plants; scurbbers for a 1000 megawatt plant use 0.5 to 0.9 million gallons per day (Mgd). This would have the effect of increasing water requirements slightly wherever coal-fired plants comprise a large share of the replacement capacity. (Appendix A.3).

3. The major long-term effects of the NEP involve the locational redistribution of impacts between and within regions. Small net movements of generating capacity can be expected from petroleum to coal supply regions. One aspect of this analysis is the question as to how much of this change will occur by 1985.

Currently most of the water required for energy is for cooling of steam electric generating facilities. In the projections for 1985 this cooling function accounts for at least 67% of the consumption by all

energy facilities in every river basin, and in a majority of them it is the only water required for energy. Thus, any trend affecting steam electric facilities may significantly affect total water use. The current tendency is to construct wet cooling towers with most new steam electric facilities. Due to evaporative loss, cooling towers consume large amounts of water compared to once-through cooling systems. New capacity added by 1985, thus, will have proportionally greater water consumption than the generating capacity already in existence in 1977, though gross water withdrawal will be proportionally smaller. This trend results from environmental protection policies independent of the NEP but will enhance consumptive water use wherever construction of generating facilities is encouraged by the NEP.

1.3 Methodology

The analysis focuses on water quantity impacts (withdrawal and consumption compared to available surface supply) at the Water Resources Council Aggregated Subarea (ASA)* level. Three river basins containing sizable coal reserves — the Ohio, Upper Mississippi, and Missouri River Basins — have been selected for more detailed analysis at the subregional level. Federal Energy Agency (FEA) Region VI** has been selected for a similarly detailed analysis because of its current dependence on oil and gas. A thorough discussion of the technical aspects of this analysis is contained in the report A Nationwide Assessment of Water Quantity Impacts of the National Energy Plan, Volume II: Regional Energy Production Capacities and Water Requirements.[2]

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*ASAs are clusters of counties approximating individual tributary river basins, portions of main stem basins, and groups of small (usually coastal) river basins.

**Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

The approach begins with national economic-energy scenarios for 1985 representing the Base Case and the NEP Initiative. Estimates of aggregate energy demand and fuel use have been disaggregated to multistate regions by the FEA using the Project Independence Evaluation System (PIES) model.[3] Steam electric generation is emphasized in the analysis because it accounts for most of the water requirements for energy. The regional demand for electricity is converted to an estimate of needed generating capacity and compared to the existing and proposed capacity expected to be on line in 1985.[4] If additional capacity is needed, it is sited by county in consideration of accessibility to the load center, proximity to water, population density, seismic activity, air quality, and rail and barge accessibility.[5] Conversely, excess capacity is retired or canceled wherever it appears reasonable under the assumptions of the scenario.

The water requirements for coal extraction activities originally were included in this study because of their potential significance in the West. Coal washing and dust control require small amounts of water wherever extraction takes place, and the revegetation of stripped land in the West requires irrigation. In the East, rainfall usually is sufficient for revegetation. It was found that these requirements are negligible at the regional scale even in the West although significant local problems may be encountered.

Coal liquefaction and gasification facilities consume water for evaporative cooling and for the chemical reactions involved in the conversion. Only a few plants have been projected in either scenario, but they could have significant local impacts.

Rates of water withdrawal and consumption have been determined for each ASA and subregion using the load factors and unit water requirements shown in Appendix A. Water availability for all uses including instream flow is assumed to equal the flow that will be exceeded 95% of the time in each critical month. Problem areas are identified wherever water demand for energy uses becomes a significant fraction of this flow (30% or more). The implications of these problems are discussed.

1.4 Limitations of the Study

This study is limited to 1985 and, therefore, cannot be expected to detect major water supply problems in the eastern United States. Previous recent trends scenario studies at ORNL have shown water shortages in the East only on certain tributaries by 1985 with some main stem shortages developing by 2000.[6,7,8]

The ASA projections for 1985 should be regarded as conservative estimates of any problems that may be identified. The comparison of aggregate basin consumption with streamflow at the point or points of exit could mask additional problems that may exist where a disproportionate amount of the consumption occurs on a small tributary or small coastal river within the basin. Using average rates of consumption rather than instantaneous peak consumption also tends to mask potential shortages. Furthermore, the 95% exceedence level tends to be higher than other measures of critical levels of streamflow, such as the 7-day/10-year low flow, which are preferred by many water resources specialists and which have legal standing in some states. These other measures of streamflow are not available for the nation as a whole, but the 7-day/10-year low

flow has been calculated for all streams in the four regions highlighted in this report. Maximum as well as average rates of water consumption have been calculated for the energy facilities in the Ohio River Basin and in FEA Region VI.

Total water use by all sectors, including domestic, commercial, industrial, and agricultural water consumption, has been considered in defining problem areas at the ASA level, but these uses were held constant between the two scenarios. Only the energy sector has been examined to determine differences between the NEP and the Base Case.

2. Water Availability Analysis

In most basins it is impossible to calculate precisely how much water is available for energy. Generally under the Riparian Doctrine, which prevails in all of the Eastern states except Delaware, Florida, and Mississippi, an unlimited amount may be taken by any user owning property adjacent to the stream as long as the use does not adversely affect the flow required by downstream users. This means that any reasonable rates of withdrawal and consumption will be supported during periods of adequate flow. Water quantity constraints are applicable only in periods of unusually low flow, during which the amount available to any user depends on established priorities of use, litigation by downstream users, and minimum flow standards. Only a few states have established precise requirements for minimum flows to support instream uses.*

The Appropriation Doctrine, which applies in all of the Western states plus Delaware, Florida, and Mississippi,** offers even less certainty as to how much water is available for energy. Generally the right to use water is independent of land ownership and can be transferred from one user to another under contractual agreements subject to the approval of a state water engineer. Approval usually depends upon verification that the water will be devoted to a beneficial use. In only two Western states, Montana and Colorado, is instream flow recognized

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*Uses that do not require withdrawal or consumption, e.g., navigation, recreation, and aquatic habitat.

**These Eastern states have permit systems that employ most of the principles of the Appropriation Doctrine without establishing priorities on use during critical periods.

as a beneficial use. Theoretically, most of the flow of any stream could be purchased for use by energy facilities. In practice, however, the amount of water available for energy is limited by the value placed on other beneficial uses, and approval for massive transfers to energy would be determined in the political arena of each state.

Although appropriative water rights are based upon volumes of water withdrawn or consumed annually, periods of seasonal low flow can constrain availability to users requiring dependable flows throughout the year. Utilities generally purchase senior rights, which give them priority over other users during the low flow, or construct reservoirs dedicated to their needs. Because users with low priority and inadequate storage may suffer during such periods, we have considered low flow in the definition of problem areas in the states practicing the Appropriation Doctrine as well as in those with the Riparian Doctrine.

Our analysis of the projected water resource impacts of energy production focuses on the seasonal period when the total water demand utilizes the greatest proportion of estimated supply. Surface water supply estimates are based on the 95% monthly discharge ("exceedence" value estimates) of 1975 Present Modified Flows.[9,10] These figures represent the ASA surface outflow that has a 95% chance of being exceeded for a given month.

The monthly exceedence values were adjusted for the 1975 level of upstream surface water consumption by ASA for all uses, to reflect the Approximate Total Surface Supply (ATSS). The most recent, available data on projected monthly water consumption by sector (i.e., domestic, manufacturing, mining, agriculture, steam electric, etc.) were obtained

from the Water Resources Council.[11] These projections are calculated by various federal governmental agencies and are reported as ASA totals to WRC. The monthly water consumption by the entire energy sector was removed from WRC's projected 1985 monthly ASA total consumption figures and replaced with the appropriate water-for-energy requirements calculated for each scenario by ORNL. In addition to consumption, rates of water withdrawal by the energy sector were calculated by ASA and subregion for the Base Case and the NEP Initiative, but withdrawal data for other uses were not available.

The estimated contribution by groundwater sources to total ASA water supply was considered in the analysis. If the groundwater portion of total water consumption exceeded 10% in any ASA, a determination was made regarding the feasibility of increased groundwater withdrawals. The determination was based on the existence of negative impacts, including

1. mining of groundwater that exhausts the water source,
2. withdrawal that diminishes spring or streamflow,
3. withdrawal that causes subsidence and fissures,
4. withdrawal that causes salt-water intrusion into freshwater aquifers.

If increased groundwater withdrawals would add to existing depletion problems within an ASA, future groundwater withdrawal was held constant at the 1975 level. Otherwise, groundwater use was assumed to increase proportionally to the increase in total water use. Interbasin water imports, exports, and surface evaporation from reservoirs were assumed to remain at 1975 levels.

The 1985 monthly consumption and water availability data were entered into a cumulative downstream accounting procedure to compute the monthly consumption totals and percentages of the availabile water (ATSS) consumed in each month. The critical water supply month for each river basin was then determined on the basis of the difference between the ATSS and total upstream 1985 consumption, and a composite file of these "critical water supply month" values was created.

3. The Effects of the NEP on Supply Infrastructure

Undoubtedly the NEP will have a significant effect on existing and proposed oil- and gas-fired generating capacity and on the plants that produce oil and gas. Many generating plants will experience early retirement or retrofitting, and hardly any new oil- and gas-fired base-load facilities or gas-fired peaking plants will be built. The outlook for replacement capacity, however, is much less clear because there are no strong incentives to build new coal-fired or nuclear plants aside from the market demand for electricity. This chapter describes the supply infrastructure projected for the Base Case and NEP Initiative and explains the final siting patterns derived by ORNL and used in the calculation of water requirements.

For the nation as a whole, under the NEP oil- and gas-fired steam electric capacities are anticipated to be less than half the amount currently planned by the utilities. Indeed, a large portion of the prime existing capacity (less than 30 years old) would have to be retired to match the NEP Initiative scenario. Of course, the brunt of this impact is in regions where oil- and gas-fired capacities currently constitute a major portion of the whole. Utility plans for FEA Region VI now have 56% of its 1985 steam electric capacity in these fuel types. This is expected to drop to 52% in the Base Case and 40% in the NEP Initiative. By far the largest portion of this is gas-fired capacity, and the disincentives for its use are even greater than those for oil. FEA Region IX* also has plans for 56% of its steam electric capacity to be fueled by oil and gas, but there, as in most other regions, oil

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*Arizona, California, and Nevada.

heavily predominates. FEA Regions I* (48%) and II** (42%) also plan to rely on oil and gas for a large portion of their electricity in 1985. The NEP is expected to cause reductions to 46% in Region IX, 21% in Region I, and 22% in Region II.

After the existing and proposed capacity has been adjusted to match each scenario as closely as possible, total base-load capacities are compared to determine how much additional capacity is needed to supply the electricity demand. In the NEP Initiative scenario, coal-fired capacity exceeds the utility plans by 21,700 megawatts (MWe). This large deficit suggests that FEA considers this the most likely replacement for oil- and gas-fired capacity. If the surplus from nuclear and hydroelectric technologies is applied against the need for coal-fired capacity, the remaining deficit is 16,000 MWe. In the Base Case the net base-load deficit is only 13,000 MWe. In both cases the needed capacity was sited as additional coal-fired plants primarily in the Ohio River Basin and Middle Atlantic area because of the high demand and proximity to coal reserves.

The Project Independence Evaluation System (PIES) model projections show a significant difference (717,500 million standard cubic feet versus 205,100 million) in synthetic gas production between the Base Case and NEP Initiative. The coal conversion facilities to produce this gas have been sited near large reserves of high-sulfur coal in the Ohio, Upper Mississippi, and Missouri River Basins.

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*Connecticut, New Hampshire, Maine, Massachusetts, Rhode Island, and Vermont.

**New Jersey and New York.

National aggregate coal demand is expected to increase, and 1985 domestic production is expected to reach 975 million short tons in the Base Case and 1175 million as a result of the NEP. Only two WRC Regions — New England and the Rio Grande — show no production in 1985. The largest amounts are extracted in the Ohio, Missouri, and Upper Colorado River Basins. Calculations of water requirements for coal extraction have been entered into the analysis, but their impact is negligible at the regional scale.

4. Regional Water Requirements

For the nation as a whole it can be concluded that there is no appreciable difference in water quantity impacts between the Base Case and NEP Initiative. Statistically the two distributions are almost identical,* and a basin-by-basin comparison shows that in most ASAs there is no difference in consumption as a percentage of the ATSS (Fig. 1). This percentage, indicating the significance of water use relative to supply, never varies by more than one percent except in the Trinity River Basin of Texas. Significantly, most of the differences are reductions attributable to the NEP. This finding, however, should not be interpreted as an optimistic prediction that water resource impacts will be negligible in 1985. There will be a considerable increase in water use for energy between 1975 and 1985, and water availability may constrain this development in certain basins.

This chapter discusses the results of the analysis at the ASA level. Each WRC region is examined in regard to differences in water withdrawal and consumption between the Base Case and NEP Initiative. Appendix B summarizes the water requirements for each WRC region. Problem areas are identified under both scenarios, and special attention is given to the implications of the NEP in ASAs where water availability may constrain energy development. Figure 2 displays the number and location of each ASA.

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*$r = .97$ at the .00001 significance level.

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WRC Region 1, New England

Total steam electric capacity varies from 23,000 MWe in the Base Case to 15,400 in the NEP Initiative. There are no coal extraction or conversion activities. By 1985 water consumption for all energy development amounts to only 84 million gallons per day (Mgd) in the Base Case and 72 Mgd in the NEP Initiative, producing a negligible effect on water availability at the ASA level. The variation between the two scenarios is only 1% of the ATSS (Appendix B.2). It is unlikely that water availability will pose a problem for energy development except, perhaps, in ASA 103 (Boston and vicinity) where consumption by all users will exceed 30% of the ATSS in either scenario (Fig. 3).

WRC Region 2, Middle Atlantic Region

In 1985, total steam electric capacity ranges from 71,300 MWe in the Base Case to 61,400 MWe in the Initiative. Coal extraction increases from 81,900 tons/day in the Base Case to 100,400 tons/day in the Initiative. Coal extraction does not require large quantities of water in humid regions (where reclamation does not require irrigation); therefore, 1985 water consumption for all energy development is governed primarily by changes in steam electric generation. The projected water consumption for all energy facilities is 395 Mgd in the Base Case and 392 in the NEP Initiative -- a negligible difference. However, cumulative upstream consumption by all users will exceed 30% of the supply in ASA 202 (Metropolitan New York), and this could constrain energy development in the area of highest demand near New York City.

The Delaware River Basin (ASA 204) currently has restrictions on a case-by-case basis against further development of water-consuming facilities without adequate storage or an alternative source to augment streamflow during periods of low flow. However, water availability is not expected to limit the energy development needed in the Delaware Valley by 1985.

WRC Region 3, South Atlantic-Gulf Region

Total steam electric capacity varies from 82,700 MWe in the Base Case to 71,900 MWe in the NEP Initiative. Coal extraction increases from 52,800 tons in the Base Case to 56,100 tons in the Initiative. Water consumption for all energy developments is governed primarily by changes in steam electric generation in Region 3 because of the low water requirements for coal extraction. The 491 Mgd required for energy facilities in the Base Case can be compared to 464 Mgd in the Initiative. This reduction, however, is negligible in areas that may have problems with water consumption. The requirement for all uses is reduced by less than 0.5% of the ATSS in every ASA when water consumption for energy is changed by the NEP Initiative scenario.

Consumption by all users exceeds 80% of the ATSS in ASAs 304 and 305 (south-central Georgia and all of Florida except the Panhandle). As with the Western states competition for water between agriculture and energy may pose an increasing problem.

WRC Region 4, Great Lakes Region

Total steam electric capacity ranges from 60,200 MWe in the Base Case to 54,800 MWe in the Initiative. The amount of coal extraction is insignificant (55 tons/day Base Case, 70 tons/day Initiative), and there are no coal conversion activities. By 1985, water consumption for steam electric generation amounts to 288 Mgd for the Base Case and 274 Mgd for the NEP, producing a negligible effect on water availability at the ASA level.

In the downstream accounting procedure, cumulative water consumption for each ASA includes facilities on the lake shores, but no estimate of availability from the lakes is included in the ATSS. Hence, water consumption is of interest, but it should not be compared to the ATSS; the percentage calculation also is misleading. Water availability is not expected to pose a constraint by 1985.

WRC Region 5, Ohio River Basin

In 1985 total steam electric capacity varies from 97,100 MWe in the Base Case to 94,100 MWe in the NEP. Coal extraction in the region increases from 1,422,500 tons/day in the Base Case to 1,685,900 tons/day in the NEP. Coal conversion facilities are also likely in the Ohio River Basin because of these vast reserves of coal found in the area. Approximately 1325 million standard cubic feet per day (MMscfd) of synthetic gas are projected to be produced in the region to meet the requirements of the Base Case scenario, and 250 MMmscfd of synthetic gas would be produced to meet requirements for the NEP Initiative scenario. All energy development in the region would require 529 Mgd for the Base

Case and 450 Mgd for the Initiative. The highest water consumption rate projected at the ASA level is 25.8% of the ATSS, and this percentage does not change between the NEP and the Base Case. Water supply problems are not apparent at the ASA level, but more detailed studies have detected potential constraints on certain tributaries, and these are discussed in Section 5.1.

WRC Region 6, Tennessee River Basin

Total steam electric generating capacity in Region 6 is the same, 24,100 MWe, for the Base Case and the NEP Initiative. Coal extraction increases from 60,300 tons/day to 70,500 tons/day from the Base Case to the Initiative. However, the variation in coal extraction is not enough to cause a significant difference in water consumption for all energy uses, approximately 203 Mgd in both scenarios. Furthermore, no problem areas are foreseen for energy development, because total consumption by all upstream users is not greater than 4% of the ATSS in either of the region's ASAs.

WRC Region 7, Upper Mississippi River Basin

Comparing the siting requirements for 1985 to existing facilities, major increases of steam electric facilities are in coal-fired and nuclear categories, 7900 MWe coal-fired and 5700 MWe nuclear, for both the NEP Initiative and the Base Case. Almost all gas-fired facilities existing in 1975 (1400 MWe) will be retired or retrofitted. A significant increase in oil-fired facilities is projected between 1975 and 1985 (4100 MWe in the Base Case and 1900 MWe in the NEP Initiative).

Consumptive water requirements will increase to 307 Mgd in the Base Case and 310 Mgd in the NEP Initiative. Comparison with the ATSS indicates that no more than 47% of the flow will be consumed by all users. The available water supply in the basin, therefore, will be sufficient to meet all consumptive requirements in the year 1985, at least on the ASA level.

WRC Region 8, Lower Mississippi River Basin

In 1985 total steam electric capacity changes from 26,200 MWe in the Base Case to 20,200 MWe in the Initiative. Coal extraction in Region 8 is insignificant, 24 tons/day Base Case and 67 tons/day Initiative. The amount of water required for all energy purposes is only 132 Mgd for the Base Case and 120 Mgd for the Initiative. There are no problem areas projected for this region; the highest percentage of consumption for all uses never exceeds 12% of the ATSS.

WRC Region 9, The Souris-Red-Rainy River Basins

WRC Region 9, the Souris-Red-Rainy, is not discussed because of the insignificant amount of energy development projected for the region (less than 0.5 Mgd consumption for energy in the Base Case and 0.3 Mgd in the Initiative).

WRC Region 10, Missouri River Basin

Steam electric capacity for the entire basin will increase to 31,800 MWe in the Base Case and 32,400 in the NEP scenario in 1985. Both scenarios project the same development of coal production. This

will result in a water consumption of 197 Mgd, utilizing 1% of the ATSS, under the NEP scenario. Generally, the Missouri River Basin is well supplied with total surface and groundwater resources, but availability varies from season to season and year to year. Unpredictable rainfall has created variations of streamflow ranging from 298,000 Mgd to 2,720 Mgd at the same point on the main stem. Periods of drought, sometimes extending for two or more years, are not uncommon for the region. Thus, reliable flows will depend upon construction of adequate storage facilities or development of groundwater as an alternative source during periods of low flow.

WRC Region 11, Arkansas-White-Red River Basins

In many areas, water supplies, both surface and underground, are insufficient to satisfy existing and/or projected demands. Many domestic water companies and municipalities have water supply problems, and serious shortfalls will inhibit growth. In some areas the supply of surface water in the summer and fall is insufficient to meet the demands for irrigation water even in a normal year. Agricultural activity over the region is expected to decrease as more and more water rights are transferred to the manufacturing and municipal sectors. Groundwater withdrawals are mainly from the Ogallala aquifer in the High Plains, and this resource is being systematically depleted. The low streamflow in the fall will have adverse effects on aquatic habitats. There tends to be a shortage of water resources for water-based recreation in the region.

The impact of the NEP Initiative relative to the Base Case on water availability in the Arkansas-White-Red Region was found to be negligible in 1985. Projected coal production in the region increases from 15 to 24 million tons per year, but this results in an increase in water consumption of less than 0.002 Mgd spread out over five of the seven ASAs. A reduction in projected oil refining capacity in the region, from 287 to 233 thousand barrels per day (Mbbld), reduces water consumption in the region by just over 0.5 Mgd in two ASAs. Finally, in the electric utility sector, a reduction in the projected electricity capacity of 120 MWe oil-fired and 2100 MWe gas-fired steam electric plants (by retirement or by cancellation of plans) results in a saving of almost 13 Mgd of water consumption, largely in ASA 1107. The total reduction in water consumption over the region amounts to about 12.5 Mgd, or about 0.04% of the total consumed by all sectors. The largest percentage reduction occurs in ASA 1107 (about 2%), but this is still small compared to the uncertainties in the data.

WRC Region 12, Texas-Gulf Region

All of the five ASAs that make up Region 12 have water problems associated with quantity and quality, involving both surface and groundwater supplies. The underground water in the Texas High Plains area (ASAs 1203 and 1204) comes from the Ogallala aquifer, the level of which is dropping because of extensive mining of water. Groundwater availability problems also exist in the Carrizo aquifer of ASA 1205. Many municipalities, Corpus Christi for example, have water supply problems which are increasing in severity. It is expected that a large portion

of irrigated agriculture will have to be retired and the water rights transferred to other sectors in order for expected growth to occur.

The projected steam electric generating capacity in WRC Region 12 is about 10,500 MWe* lower for the NEP Initiative than for the Base Case. An increase in lignite production in the NEP Initiative relative to the Base Case results in an increase of water consumption of only about 0.003 Mgd. The total reduction in the projected water consumption between the two scenarios for the whole region is 70 Mgd, representing only about 0.3% of the total consumption by all sectors. The largest relative reductions (1 to 2%) occur in ASAs 1201 and 1202. At the ASA level these reductions are not significant, but the savings in electric generation and oil refinery capacity could alleviate some local water problems over the region.

WRC Region 13, Rio Grande River Basin

Changes in projected water consumption levels between the NEP Initiative and the Base Case for the Rio Grande Region are negligible in terms of the total water consumption for all sectors. The projected installed electrical capacity for the region differs by 900 MWe. This is actually more than a 40% reduction in projected capacity, but the water savings are only 3.7 Mgd spread over four ASAs. An almost 50% reduction in projected oil refining capacity would save another 0.5 Mgd.

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*This rather large reduction in total capacity results primarily from the retirement of gas-fired steam electric plants. In the ORNL projections no replacement capacity was sited because the remaining capacity was adequate to meet the electricity demands forecasted by FEA.

Projected levels of coal production between the two scenarios remain unchanged. The total saving of 4.2 Mgd for the whole region is only about 0.04% of the water consumed by all sectors. Almost all of the reduction occurs in ASA 1302, where it amounts to 0.1% of the total for all sectors.

WRC Region 14, Upper Colorado River Basin

The potential for energy development in the region will create intense competition for the transfer of water rights, in which the energy industries will have an enormous edge over agriculture with its low economic value. There will be a demand for strict regulation of water rights transfers to protect the viability of streams in the region. Large upstream users, such as oil shale projects in the White River area, could deplete flows to the point of adversely affecting instream flows needed for fish, other wildlife, and recreation. Water has already been allocated for future expansion of the Denver metropolitan area, but increases in interbasin transfer likely will be challenged by West Slope users.

The greatest difference between the Base Case and the NEP Initiative for the Upper Colorado Region is in the projected level of coal mining, doubling from 56 million tons per year to 112 million. The water consumption would increase by 0.02 Mgd, and oil refining levels would reduce from 26.4 Mbbld to 18.5 Mbbld, nearly all of it in ASAs 1401 and 1402, but the saving in water is much less than 1 Mgd. There is no difference in electrical generating capacity in the region between the two scenarios. Also, the two scenarios project the same level of oil

shale extraction of 50 Mbbld, which would consume about 7 Mgd, most of it in ASA 1402 and some in ASA 1401. Compared with the total water consumption by all sectors the increase in water consumption for the NEP Initiative is negligible at the regional and ASA levels.

WRC Region 15, Lower Colorado River Basin

The Lower Colorado Region is severely deficient in water. Its growing needs currently are being met by mining water at a rate considerably greater than natural replenishment of the aquifer. Surface streamflows in the region are extremely variable. The Central Arizona Project, scheduled for completion in 1985, will meet only some 60% of Arizona's present water deficiencies. Official contract requests for water from the Central Arizona Project total about five times the water supply that will be available.

The projected electric generating capacity for the region is about 1200 MWe less for the NEP than for the Base Case. This represents a reduction of about 10% in the steam electric capacity and would reduce water consumption by about 5 Mgd. The coal mining rate is almost doubled in the NEP, from 7.5 to 14.1 million tons per year, but this increases the consumption by only about 0.003 Mgd. A reduction in the projected oil refinery capacity in the region from 321 Mbbld to 267 Mbbld will reduce consumption by another 0.5 Mgd. The total change in projected water consumption due to the NEP would, therefore, be a reduction of 5.5 Mgd over the region, compared with a Base Case total of 7875 Mgd in all sectors, i.e., only a 0.07% reduction.

WRC Region 16, The Great Basin

A variety of water quantity problems exist in the Great Basin Region. In Utah there are several areas where water supplies are insufficient for expanding irrigation needs. Surface waters are limited and highly variable in the region, but so far groundwater sources have not been developed to any significant degree. Current laws in Nevada prohibit mining of underground water supplies.

In the Great Basin Region the only differences in projected energy activity levels in going from the Base Case to the NEP are a reduction of oil refining capacity from 214 to 148 Mbbld and an increase in coal production from 0.12 to 0.36 million tons per day. These changes would result in a net reduction of water consumption by 0.7 Mgd. Compared with a total consumption of 14,800 Mgd for all sectors, these changes are negligible.

WRC Region 17, Columbia-North Pacific Region

The projected electric generating capacity for the Columbia-North Pacific Region for 1985 is overwhelmingly hydroelectric and nuclear. Adoption of the NEP Initiative therefore would only reduce the oil steam electric capacity by 150 MWe, producing a reduction in water consumption of 0.6 Mgd. A small difference in coal production in ASA 1705 would increase water consumption by a negligible amount in the NEP Initiative, and a reduction in oil refining capacity for ASAs 1705 and 1706 would result in a reduction of 1.3 Mgd. In these two aggregated subareas the projected total savings of about 1.9 Mgd would represent less than a 1% change in the total consumption by all sectors.

WRC Region 18, California-South Pacific Region

Adoption of the NEP Initiative in the California-South Pacific Region would mean a difference in oil-fired steam electric capacity of just over 9,000 MWe from that projected in the Base Case, or a loss of about one-third of the total steam electric capacity in the region.* This would result in a saving of 23 Mgd of water, spread out among ASAs 1804, 1805, and 1806. A reduction in refining capacity from 2100 to 1800 Mbbld would result in a further saving of almost 15 Mgd. The total potential reduction in water consumption over the region amounts only to 0.6% of the water consumed by all sectors.

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*This large reduction is necessary to match the regional projections produced by the PIES model. ORNL has not sited replacement capacity because of the large surpluses apparent in adjacent regions.

5. Subregional Water Requirements for Energy in Selected Basins

Subregional studies that are focused on smaller tributary basins and that use more restrictive measures of water availability have been performed in the Ohio, Upper Mississippi, and Missouri River Basins and in FEA Region VI. The 7-day/10-year low flow has been calculated for each subregion, and 10% of this figure has been assumed to be available for energy purposes. Rates of water consumption are for steam electric facilities only; comparable data are not available for other sectors at this level of spatial detail. The results of the analysis are discussed in the following sections.

5.1 The Ohio River Basin

The NEP Initiative will have no greater impact than the Base Case, but in either scenario there will be negative impacts on the water resources of the region. The Ohio River Basin contains one of the major concentrations of economic activity in the nation and is the area most likely to experience future energy growth due to its large coal reserves. Applying the Ohio River Basin Commission's guideline that 10% of the 7-day/10-year low flow is a critical level for water consumption by the energy sector, only SR* 507 (the Big Sandy-Guyandotte; 10.8% Base Case, 11.0% Initiative) would be identified as a problem area in 1985, with SR 502 (the Monogahela; 7.5% Base Case, 7.8% Initiative) consuming the next highest percentage of the low flow (Appendix C.1). These figures

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*Subregions (SRs) are almost identical to WRC subareas except that ORNL has changed the designation of a few counties to more closely approximate the hydrologic basins. SRs apply in the Ohio River Basin and FEA Region VI. Seven-day/ten-year low-flow estimates for SRs in these regions were calculated using ORNL's Water Analysis System (WAS) model.[12]

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however, represent average consumption by all plants in the region. If all of the base load plants on a given tributary were running at or near maximum capacity during the low-flow period, consumption also would equal or exceed 10% in SR 502 (the Monongahela), SR 511 (the Green), and SR 501 (the Allegheny) (Appendix C.2). It is significant that in a basin the size of the O io, situated in the "water rich" eastern United States, some tributaries may experience water supply problems in meeting energy requirements at low flow. This suggests the beginning of a water supply problem that may constrain energy development after 1985.

5.2 The Upper Mississippi River Basin

On the ASA and subregional levels by the year 1985, no major supply problems were detected for either scenario. However, by 1985 localized water supply problems could occur for energy development in SA* 713 (the Illinois River), SA 701 (the Minnesota River), and portions of SA 710 (the Cedar River). Depending on the specific sites, it may be necessary to provide reservoirs or short-term storage facilities to maintain water supplies for generation in these areas during critical conditions.

In many areas within the basin, low-flow periods coupled with high consumptive use have caused water shortage problems for instream uses such as navigation, recreation, fish and wildlife maintenance, water quality control, and hydroelectric generation. Areas with such problems

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*Subareas (SAs) are clusters of counties approximating small tributary basins and short segments of main stem basins. They are defined by the Water Resources Council; in this study the designation applies in the Upper Mississippi and Missouri River Basins. Seven-day/ten-year low flow estimates for SAs in these regions were obtained from various souces by ANL.

include the Illinois, Upper Rock, Middle and Upper Cedar, Des Moines, and Upper Mississippi Rivers. Increased consumptive use for energy and nonenergy purposes by 1985 would further diminish streamflow and aggravate the situations there.

5.3 The Missouri River Basin

Based solely upon consumptive water requirements for electric generation, surface water supply could be a problem in several subregions in either scenario. It is estimated that steam electric facilities will consume more than 100% of the 7-day/10-year low flow of the Powder River in northeastern Wyoming (SA 1009), the North Platte River in southeastern Wyoming (SA 1018), and the South Platte River in Colorado (SA 1019); about 95% of the flow of the Platte River in Nebraska (SA 1021); 50% of the Smoky Hill River in Kansas (SA 1026) and the Grand River in Missouri (SA 1028); and 25% of the Cheyenne River in eastern Wyoming and 25% in southeastern South Dakota (SA 1012). In these areas, if water demands are to be met for either scenario, augmentation from reservoirs or groundwater and/or use of less water-consumptive technologies will have to be the rule.

5.4 FEA Region VI

The NEP causes no impact significantly different from that of the Base Case in any subregion of Region VI, but water problems are apparent at low flow in the Arkansas-Keystone (SR 1106), the North Canadian (SR 1110), the Neosho-Verdigris (SR 1107), the Sabine (SR 1201), the Trinity (SR 1203), the Middle and Lower Brazos (SRs 1206 and 1207), the Lower Pecos (SR 1307), the Rio Grande-Amistad (SR 1304), the Rio Grande-Falcon

(SR 1308), and Lower Rio Grande (SR 1309) Rivers and in the Galveston Bay-San Jacinto (SR 1204), Lower Colorado-Bernard-Coastal (SR 1209), Central Texas Coastal (SR 1210), and Nueces-Southwestern Texas Coastal (SR 1211) Basins. Savings from the NEP Initiative tend to alleviate some of the problems anticipated with the Base Case, but in no instance is the difference great enough to cause a problem subregion to meet the 10% of the 7-day/10-year low-flow guideline.

In the more restrictive calculation in which all base-load plants on each tributary are assumed to be operating at or near maximum capacity during the low-flow period, the White River (SR 1101) and the Louisiana Coastal Area (SR 808) are defined as problem areas in the Base Case but not in the NEP Initiative scenario.

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APPENDIX A

ASSUMPTIONS AND TECHNICAL VALUES

The purpose of this appendix is to describe the assumed levels of national electricity demand, heat rates, load factors, unit water requirements, and siting criteria that determine the estimates of generating capacities and water requirements for each ASA and subregion. They are provided here in a condensed form for the convenience of the reader to facilitate comparison with the assumptions of other modeling efforts.

The siting procedures developed at ORNL are passive in regard to scenario projections of total electricity demand and generation and fuel-type mix. Siting patterns and water requirements for numerous scenarios can be estimated for comparative purposes. The generation values implicit in this analysis vary from 3,310,490 gigawatt hours (GWh) in the Base Case to 3,060,750 GWh in the NEP scenario.

A.1 Heat Rates

Heat rates indicate the amount of input (in thermal units) required to generate a given amount of electricity. In the modeling procedure used by ORNL, as in most projections of this type, the demand for electricity is estimated and then converted to fuel use (using the heat rates shown in Table A.1).

A.2 Load Factors

The load factor for each technology indicates the portion of its maximum potential generation that is anticipated to be produced over a sustained period of time. Base-load plants are those which operate most of the time and, thus, have high load factors (0.40-0.80). In contrast, peaking plants — mostly oil- and gas-fired internal combustion turbines

Table A.1. Federal Energy Administration heat rates for 1985 by census region (in Btu/kWhr)

Generating plant type	New England 1	Mid Atlantic 2	E. N. Central 3	W. N. Central 4	South Atlantic 5	E. S. Central 6	W. S. Central 7	Mountain 8	Pacific 9
Coal – conventional steam	9,772	10,226	10,268	9,981	10,237	10,144	9,489	10,812	10,534
Coal – advanced	7,584	7,584	7,584	7,584	7,584	7,584	7,584	7,584	7,584
Oil – conventional steam	10,699	10,699	10,699	10,699	10,699	10,886	10,699	10,699	10,699
Oil – internal combustion	12,757	10,484	12,152	13,121	12,223	11,997	12,160	12,364	11,203
Gas – conventional steam	15,210	11,857	11,650	11,677	11,118	11,203	10,382	11,209	10,030
Gas – internal combustion	8,071	7,468	11,453	9,590	13,820	10,164	10,000	7,527	11,384
Hydro – conventional	9,723	9,723	9,723	9,723	9,723	9,723	9,723	9,723	9,723
Hydro – pumped storage	13,615	13,651	13,651	13,651	13,651	13,651	13,651	13,651	13,651
Nuclear – conventional	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037
Nuclear – advanced	8,532	8,532	8,532	8,532	8,532	8,532	8,532	8,532	8,532
Geothermal	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037
Solar	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037	10,037
Coal – Syngas	10,208	10,208	10,208	10,208	10,208	10,208	10,208	10,208	10,208

Source: Federal Energy Administration.

and pumped storage generating facilities — operate only during short periods of peak demand and have load factors of less than 0.20.

The assumed load factors are crucial in determining the amount of capacity needed to match the scenario demand for generation by each technology and fuel type. The estimate of regional capacity is particularly sensitive to load factors because some regions are heavily oriented toward gas and oil while others are oriented toward coal. The load factors assumed by FEA and the National Laboratories are displayed in Table A.2.

A.3 Unit Water Requirements

Unit water requirements for a generating plant vary according to the heat rate of the specific fuel and technology employed, the type of cooling system, and the heat rise permitted for the receiving water body. Other site-specific factors, such as seepage from a cooling pond into a groundwater reservoir, are less easily defined at the regional scale. We have chosen to apply average water withdrawal and consumption rates by fuel type and cooling option (Table A.3).

Table A.2. Federal Energy Administration load factors for 1985 by census region

Generating plant type	New England 1	Mid Atlantic 2	E. N. Central 3	W. N. Central 4	South Atlantic 5	E. S. Central 6	W. S. Central 7	Mountain 8	Pacific 9
Coal – conventional steam	0.61	0.50	0.50	0.51	0.51	0.47	0.70	0.5940	0.36
Coal – advanced	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Oil – conventional steam	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Oil – internal combustion	0.08	0.36	0.08	0.08	0.08	0.08	0.08	0.08	0.18
Gas – conventional steam	0.36	0.36	0.36	0.36	0.36	0.36	0.45	0.36	0.36
Gas – internal combustion	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Hydro – conventional	0.44	0.84	0.55	0.66	0.44	0.46	0.28	0.5533	0.67
Hydro – pumped storage	0.08	0.08	0.08	0.09	0.08	0.08	0.09	0.08	0.08
Nuclear – conventional	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Nuclear – advanced	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Geothermal	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Solar	0.79	0.80	0.79	0.80	0.80	0.79	0.79	0.7500	0.80
Coal – Syngas	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70

Source: Federal Energy Administration.

Table A.3. Unit water requirements by plant type, fuel type, and cooling option

Plant type or activity	Fuel type	Cooling option	Withdrawal (Mgd)	Consumption (Mgd)	Plant capacity
Steam electric generation	Nuclear	Once through	1400	4	1000 MW(e)
		Cooling pond	42	26	1000 MW(e)
		Wet cooling tower	28	17	1000 MW(e)
		Dry cooling tower	0.3	0	1000 MW(e)
		Natural draft cooling tower	28	17	1000 MW(e)
		Mechanical draft cooling tower	28	17	1000 MW(e)
		Canal	42	26	1000 MW(e)
	Fossil[a]	Once through	830	3	1000 MW(e)
		Cooling pond	25	15	1000 MW(e)
		Wet Cooling tower	17	10	1000 MW(e)
		Dry cooling tower	0.2	0	1000 MW(e)
		Natural draft cooling tower	17	10	1000 MW(e)
		Mechanical draft cooling tower	17	10	1000 MW(e)
		Canal	25	15	1000 MW(e)
Coal liquefaction			20	20	50,000 bbl/day
Coal gasification			19	16	250 MMscfd
Oil refining			10	0.5	50,000 bbl/day (crude charge)
Underground coal mining					
(Appalachian Reserve)			0.0033	0.00027	1 million short tons/year
(Eastern Interior Reserve)			0.0036	0.00027	1 million short tons/year
(All western reserves)			0.036	0.036	1 million short tons/year
Surface coal mining					
(Appalachian Reserve)			0.0030	0.00008	1 million short tons/year
(Eastern Interior Reserve)			0.0033	0.00012	1 million short tons/year
(All western reserves)			0.20	0.20	1 million short tons/year

[a]Scrubbers add 1 Mgd to withdrawal and consumption rates.

Sources:

T. H. Pigford, M. J. Keaton, B. J. Mann, and G. L. Sessler, *Comprehensive Standards: The Power Generation Case*, Teknekron Inc. (March 1975).

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Engineering Studies at ANL, LASL, and ORNL.

APPENDIX B

REGIONAL WATER WITHDRAWAL AND CONSUMPTION FOR ENERGY AND OTHER USES

Table B.1. 1975 and 1985 water consumption by energy and other sectors by WRC region

WRC region	1975 major uses and steam electric use (percentage of total consumption)		1975 total consumption by all sectors (Mgd)	1985 consumption by energy (Mgd)	
				Base	NEP
New England	Manufacturing	45.0	472	83.7	71.5
	Domestic uses	36.0			
	Steam electric	4.6			
Middle Atlantic	Domestic uses	40.0	1,825	398.6	391.6
	Manufacturing	34.0			
	Steam electric	4.6			
South Atlantic–Gulf	Irrigation	60.0	5,276	491.0	463.7
	Steam electric	3.5			
Great Lakes	Manufacturing	57.0	2,541	287.6	274.1
	Steam electric	6.7			
Ohio	Manufacturing	46.0	1,706	528.5	449.9
	Steam electric	17.3			
Tennessee	Manufacturing	43.0	311	203.3	203.1
	Steam electric	18.0			
Upper Mississippi	Manufacturing	25.2	1,028	339.0	316.4
	Domestic uses	21.3			
	Steam electric	13.1			
Lower Mississippi	Irrigation	75.0	4,515	132.1	120.1
	Steam electric				
Souris–Red–Rainy	Irrigation	30.0	86	0.4	0.3
	Steam electric				
Missouri	Irrigation	91.0	14,432	205.4	209.9
	Steam electric				
Arkansas–White–Red	Irrigation	90.0	8,176	172.5	158.7
	Steam electric	0.5			
Texas–Gulf	Irrigation	84.0	11,693	347.5	290.6
	Steam electric	1.0			
Rio Grande	Irrigation	90.0	4,606	10.0	6.2
	Steam electric				
Upper Colorado	Irrigation	90.5	2,680	88.9	95.6
	Steam electric				
Lower Colorado	Irrigation	87.0	4,778	81.4	77.5
	Steam electric				
The Great Basin	Irrigation	90.0	4,319	7.2	7.1
	Steam electric				
Columbia–North Pacific	Irrigation	90.0	13,804	96.5	94.7
	Steam electric				
California–South Pacific	Irrigation	90.0	29,330	67.2	50.3
	Steam electric				

Source: Water Resources Council, 1975 National Water Assessment.

Table B.2. Surface water supply and 1985 water requirements for energy and other sectors by ASA

ASA	Consumption by all sectors[a] (Mgd)		Consumption by energy[b] (Mgd)		Approximate total surface supply[a] (Mgd)	Cumulative upstream consumption by all sectors as a percentage of supply[b]		Withdrawal by energy[b] (Mgd)	
	Base	NEP	Base	NEP		Base	NEP	Base	NEP
101	114.6	114.4	2.6	2.4	7,054.6	1.6	1.6	891.6	832.8
102	54.4	54.7	23.3	23.5	1,382.5	3.9	4.0	1,350.5	1,340.1
103	172.3	167.2	32.9	27.6	541.0	31.9	30.9	3,453.4	2,460.5
104	115.1	111.8	12.7	9.3	545.4	21.1	20.5	3,727.7	3,126.9
105	161.0	159.4	10.1	8.5	1,949.3	8.3	8.2	1,103.0	715.4
106	29.7	29.7	0.1	0.1	1,510.1	2.0	2.0	15.1	15.1
201	180.6	180.1	16.4	15.9	2,456.9	7.4	7.3	264.8	23.8
202	927.3	915.6	45.0	32.8	3,560.3	31.1	30.8	6,942.4	3,828.2
203	750.2	743.7	153.4	146.8	3,022.0	24.8	24.6	4,243.5	4,147.2
204	300.5	311.6	115.5	126.8	2,591.7	11.6	12.0	1,396.3	1,410.8
205	431.8	431.8	102.3	102.8	5,761.2	25.7	25.8	2,475.8	2,475.8
206	227.9	228.9	24.3	25.3	1,326.2	17.2	17.3	801.5	801.5
301	293.4	291.6	63.7	61.8	2,325.6	12.6	12.5	1,812.8	1,807.5
302	541.3	541.3	123.5	123.5	5,409.1	10.0	10.0	2,574.3	2,289.5
303	397.3	397.9	98.9	99.5	5,082.7	7.8	7.8	1,002.9	919.4
304	2,196.2	2,192.5	36.9	33.2	2,687.5	81.7	81.6	2,825.4	1,733.8
305	4,160.4	4,148.3	47.1	35.0	3,397.2	122.5	122.1	2,525.8	1,610.4
306	238.8	239.5	37.8	38.5	5,847.2	4.1	4.1	672.5	644.8
307	271.1	270.3	33.3	32.5	11,309.1	2.4	2.4	954.7	951.6
308	299.4	300.4	21.5	22.5	6,014.0	5.0	5.0	1,376.1	1,376.1
309	174.6	174.8	17.3	17.6	2,250.5	7.8	7.8	207.4	207.1
401	161.3	160.8	2.4	1.9	1,946.7	8.3	8.3	225.8	169.3
402	269.7	270.0	13.0	13.3	2,901.4	9.3	9.3	1,361.4	1,350.1
403	887.4	888.2	75.4	76.2	793.1	111.9	112.0	5,636.4	5,449.4
404	566.2	566.0	26.7	26.5	7,671.0	7.4	7.4	2,636.1	2,517.9
405	178.1	176.0	29.5	27.4	2,300.4	7.7	7.7	535.9	415.5
406	712.1	707.0	69.6	64.4	846.6	84.1	83.5	4,269.9	3,696.1
407	573.0	574.0	42.0	43.0	814.0	70.4	70.5	2,276.1	2,276.1
408	196.7	196.5	21.4	21.2	3,771.7	5.2	5.2	3,658.9	3,514.2
501	141.2	143.1	53.4	56.2	1,619.6	8.7	8.8	698.4	698.4
502	922.7	890.5	188.1	156.0	6,009.8	25.3	24.9	5,799.7	5,749.2
503	304.1	304.9	24.8	25.6	1,180.8	25.8	25.8	1,291.3	1,234.3
504	154.4	155.5	30.5	31.6	1,262.9	12.2	13.3	781.4	781.4
505	345.8	315.0	92.5	61.6	28,946.6	10.0	9.8	3,418.2	3,081.0
506	375.8	322.8	54.9	51.9	2,101.6	15.5	15.4	2,269.5	2,196.8
507	125.6	125.8	66.7	66.9	2,654.1	4.7	4.7	1,737.6	1,648.4
601	410.5	411.2	127.2	127.9	12,239.5	3.4	3.4	1,531.0	1,531.0
602	175.3	176.0	74.5	75.2	15,561.8	3.8	3.8	1,839.6	1,839.6
701	180.7	181.4	38.5	39.2	2,650.5	6.8	6.8	357.1	296.3
702	1...6	128.0	19.7	20.1	8,593.1	3.6	3.6	516.3	508.2
703	374.3	374.1	85.4	85.3	12,112.4	5.6	5.6	1,094.9	1,033.2
704	300.8	273.5	163.7	135.7	13,940.8	7.0	6.8	1,354.4	1,229.0
705	272.3	272.9	33.2	33.9	39,160.9	16.8	16.8	2,788.8	2,623.7
801	95.4	94.3	4.9	3.8	80,604.9	11.8	11.7	1,216.9	842.0
802	336.6	337.1	59.8	60.3	95,482.2	11.0	10.9	676.7	652.2
803	1,056.9	1,050.2	63.0	56.1	98,653.5	11.7	11.6	3,565.8	2,917.5
901	344.0	343.9	0.4	0.3	695.2	49.5	49.5	88.8	68.9
1001	2,123.9	2,123.9	0.0	0.0	9,894.6	21.5	21.5	0.0	0.0
1002	10,460.8	10,460.8	0.0	0.0	7,896.4	132.5	132.5	0.0	0.0
1003	1,256.0	1,256.0	0.0	0.0	455.3	275.9	275.9	0.0	0.0
1004	11,225.9	11,226.6	15.9	16.6	11,984.1	93.7	93.7	134.1	134.1

Table B.2 (continued)

ASA	Consumption by all sectors[a] (Mgd)		Consumption by energy[b] (Mgd)		Approximate total surface supply[b] (Mgd)	Cumulative upstream consumption by all sectors as a percentage of supply[b]		Withdrawal by energy[b] (Mgd)	
	Base	NEP	Base	NEP		Base	NEP	Base	NEP
1005	1,943.6	1,943.6	7.8	7.8	28,410.3	53.8	53.8	780.3	780.3
1006	955.9	955.9	0.0	0.0	32,461.5	50.1	50.1	5.1	0.0
1007	13,576.8	13,577.7	33.4	34.3	14,008.9	96.9	96.9	256.4	256.4
1008	14,069.9	14,070.1	11.0	11.2	25,917.1	106.7	106.7	47.1	44.7
1009	410.1	410.4	31.2	31.5	33,673.3	49.5	49.5	2,002.4	1,968.7
1010	4,650.4	4,656.4	37.6	43.6	5,270.4	88.2	88.4	66.0	73.0
1011	246.0	247.7	63.1	64.9	67,391.2	32.0	32.0	977.6	1016.1
1101	25.1	25.1	0.0	0.0	2,506.6	1.0	1.0	2.4	0.0
1102	1,768.2	1,767.8	9.3	9.0	2,512.4	70.4	70.4	33.4	15.5
1103	2,215.8	2,216.0	10.8	11.8	4,152.7	183.1	183.1	616.1	614.0
1104	494.4	494.4	58.5	58.5	4,709.7	83.9	83.9	950.5	913.1
1105	3,345.0	3,344.0	13.3	12.3	4,123.0	81.1	81.1	223.2	225.8
1106	6,418.1	6,415.7	11.0	8.6	5,314.2	120.8	120.7	17.0	12.8
1107	385.4	379.2	65.1	58.7	635.3	66.2	65.2	158.6	151.4
1201	395.6	394.2	43.9	42.5	705.1	56.1	55.9	873.0	369.1
1202	1,075.9	1,046.0	104.1	73.3	816.1	131.8	128.2	610.2	538.2
1203	679.7	675.4	95.0	90.7	784.8	86.6	86.1	361.0	299.3
1204	839.2	831.7	56.4	48.3	909.8	92.2	91.4	533.5	369.0
1205	1,093.0	1,089.4	39.8	35.9	1,652.1	66.2	65.9	616.6	605.1
1301	11.3	11.3	0.0	0.0	21.4	52.6	52.6	1.0	1.0
1302	544.4	541.7	4.5	1.8	642.3	86.5	86.1	7.0	2.6
1303	182.0	182.0	2.9	2.9	1,285.9	64.0	63.8	4.5	4.2
1304	85.8	85.7	0.1	0.0	200.0	42.9	42.9	0.1	0.0
1305	655.8	655.3	1.8	1.3	1,843.4	80.2	80.1	2.7	1.9
1401	5,351.2	5,354.5	49.7	53.0	4,564.5	117.2	117.3	167.7	224.9
1402	3,385.2	3,385.4	0.8	1.0	7,232.3	46.8	46.8	12.7	18.0
1403	2,552.0	2,557.7	35.8	41.5	4,926.4	120.5	120.6	208.8	349.7
1501	196.5	197.9	17.1	18.8	281.5	69.8	70.3	65.4	101.7
1502	1,248.5	1,249.8	40.4	41.7	10,178.0	41.8	41.8	447.1	447.1
1503	2,806.8	2,802.1	21.6	16.9	3,310.8	84.8	84.6	56.2	49.0
1601	3,853.0	3,855.1	1.7	1.8	8,430.3	45.7	45.7	33.3	33.3
1602	2,120.3	2,120.3	0.0	0.0	3,429.2	61.8	61.8	0.0	0.1
1603	5,108.5	5,108.6	3.2	3.3	6,448.3	79.2	79.2	4.9	4.9
1604	2,347.9	2,348.0	2.1	2.1	3,091.0	76.0	76.0	18.9	18.9
1701	1,966.4	1,966.4	0.0	0.0	12,952.0	15.2	15.2	0.0	0.0
1702	6,986.8	6,986.9	46.4	46.5	73,712.3	24.8	24.8	74.2	74.2
1703	8,521.2	8,521.2	0.0	0.0	11,360.9	75.0	75.0	0.0	0.0
1704	859.7	859.7	0.0	0.0	19,346.7	48.4	48.4	0.0	0.0
1705	1,443.0	1,442.5	33.4	32.9	88,180.5	22.3	22.3	90.8	64.2
1706	559.7	559.5	15.5	15.3	8,592.6	6.5	6.5	31.6	25.2
1707	2,864.1	2,864.1	0.0	0.0	1,998.8	143.3	143.3	0.0	0.0
1801	2,345.5	2,345.4	0.3	0.2	3,083.4	76.1	76.1	92.5	61.3
1802	3,546.4	3,546.4	11.1	11.1	8,661.4	40.9	40.9	17.7	17.7
1803	10,729.0	10,728.3	0.7	0.0	9,903.8	161.5	161.5	1.1	0.0
1804	1,035.9	1,032.9	8.3	5.3	788.2	131.4	131.1	962.3	270.3
1805	140.1	139.7	10.1	9.3	200.4	69.9	69.7	3,118.7	2,848.8
1806	2,362.4	2,353.1	33.9	24.6	2,933.3	80.5	80.2	5,681.0	4,426.8
1807	10.2	10.2	0.0	0.0	1,023.1	1.0	1.0	0.0	0.0

[a]Water Resources Council, 1975 National Water Assessment.
[b]Calculated by ORNL.

APPENDIX C

SUBREGIONAL WATER WITHDRAWAL AND CONSUMPTION FOR STEAM ELECTRIC GENERATION

Table C.1. Downstream accounting of water consumption in the Ohio River Basin by steam electric facilities, using system load factors

Subregion	Stream	7-day/10-year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
501	Allegheny	704.1	285.2	33.5	285.2	34.6	4.8	4.9
502	Monongahela	277.7	412.8	20.8	412.8	21.6	7.5	7.8
504	Upper Ohio	374.7	834.9	10.4	834.9	11.0	2.8	2.9
503	Muskingum	4,554.3	3,248.5	58.8	3,248.5	60.7	2.7	2.8
505	Kanawha	904.4	326.4	9.9	326.4	10.3	1.1	1.1
506	Scioto	187.3	38.9	0.2	38.9	0.2	0.1	0.1
507	Big Sandy–Guyandotte	51.0	8.4	5.5	8.4	5.6	10.8	11.0
508	Great Miami	180.9	399.4	2.6	342.3	2.6	1.4	1.4
509	Middle Ohio	7,719.7	2,895.3	66.6	2,888.3	69.1	2.7	2.8
510	Kentucky–Licking	129.2	101.5	1.4	30.4	1.1	1.1	0.9
511	Green	219.6	113.1	13.0	113.1	13.4	5.9	6.1
515	White	465.1	615.0	15.6	580.4	11.9	3.4	2.6
512	Wabash	1,427.7	1,656.2	37.9	1,614.3	38.6	3.7	3.5
514	Lower Ohio	12,920.0	2,190.7	37.5	1,924.6	37.9	2.4	2.5
516	Base of the Ohio	29,909.8	1,008.1	5.5	1,008.1	6.0	1.1	1.1

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
Source: Calculated by ORNL.

Table C.2. Downstream accounting of water consumption in the Ohio River Basin by steam electric facilities, using 100% load factor

Subregion	Stream	7-day/10-year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
501	Allegheny	704.1	565.9	68.7	565.9	66.6	9.8	9.5
502	Monongahela	277.7	818.0	42.7	818.0	41.1	15.4	14.8
504	Upper Ohio	374.7	1,683.5	22.1	1,683.5	21.0	5.9	5.6
503	Muskingum	4,554.3	6,454.5	109.4	6,454.5	105.4	5.3	5.1
505	Kanawha	904.4	645.7	20.4	645.7	19.7	2.3	2.2
506	Scioto	187.3	78.5	0.3	78.5	0.3	0.2	0.2
507	Big Sandy–Guyandotte	51.0	17.8	11.9	17.8	11.6	23.3	22.7
508	Great Miami	180.9	690.3	5.9	848.8	4.9	3.3	2.7
509	Middle Ohio	7,719.7	5,801.3	134.9	5,820.3	129.8	5.4	5.2
510	Kentucky–Licking	129.2	64.3	3.3	261.7	2.3	2.6	1.8
511	Green	219.6	239.1	28.3	239.1	27.4	12.9	12.5
515	White	465.1	1,170.3	36.1	1,266.3	23.0	7.8	4.9
512	Wabash	1,427.7	3,242.4	70.9	3,358.9	67.5	7.5	6.3
514	Lower Ohio	12,920.0	3,978.3	80.7	4,717.4	75.6	4.9	4.6
516	Base of the Ohio	29,909.8	2,091.0	11.4	2,091.0	12.2	2.2	2.0

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
Source: Calculated by ORNL.

Table C.3. Downstream accounting of water consumption in the Upper Mississippi basin by steam electric facilities, using system load factors

Subregion	Stream	7-day/10-year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
701	Minnesota	103.4	80.2	4.1	34.3	3.9	3.97	3.77
702	Mississippi	1,990.0	276.8	34.5	261.9	35.3	1.94	1.97
703	St. Croix	711.0	0	0	0	0	0	0
704	Chippewa	1,357.0	0	0	0	0	0	0
705	Mississippi	3,709.0	249.5	14.1	249.5	14.2	1.42	1.44
706	Wisconsin	1,810.0	266.7	5.7	258.7	5.9	3.15	3.26
707	Mississippi	8,892.0	166.8	1.7	166.8	1.7	0.68	0.69
708	Rock	942.0	280.1	38.3	264.3	38.3	4.66	4.66
709	Des Moines	81.4	33.0	5.6	22.9	5.5	6.88	6.76
710	Mississippi	10,198.0	614.9	39.9	579.1	39.7	1.41	1.41
711	Mississippi	11,588.0	23.3	0.1	16.1	0	1.24	1.25
712	Illinois	2,077.0	82.6	50.3	78.2	47.9	2.42	2.31
713	Illinois	2,316.0	1,210.2	81.4	1,127.0	81.3	5.69	5.58
714	Mississippi	31,275.0	2,788.6	33.2	2,623.5	33.9	1.60[b]	1.61[b]

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
[b]Includes energy-related consumptive use in the Missouri Basin.
Source: Calculated by ANL.

Table C.4. Downstream accounting of water consumption in the Missouri River basin by steam electric facilities, using system load factors

Subregion	Stream	7-day/10 year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
1002	Missouri	608.0	0	0	0	0	0	0
1003	Missouri	2326.0	0	0	0	0	0	0
1004	Missouri	1314.0	0	0	0	0	0	0
1005	Milk	2.8	0	0	0	0	0	0
1006	Missouri	1869.0	0	0	0	0	0	0
1007	Yellowstone	648.0	0	0	0	0	0	0
1008	Bighorn	390.0	0	0	0	0	0	0
1009	Powder	0.65	3.5	2.3	3.5	2.5	354.0	384.0
1010	Yellowstone	944.0	130.0	13.6	130.0	14.1	1.7	1.8
1011	Missouri	4444.0	734.7	5.2	734.7	5.2	0.47	0.49
1012	Cheyenne	1.94	0.7	0.5	0.7	0.5	25.8	25.8
1013	Missouri	3185.0	44.8	2.1	44.8	2.1	0.07	0.07
1014	Missouri	3510.0	0	0	0	0	0.68	0.70
1015	Niobrara	136.0	0	0	0	0	0	0
1016	James	0.91	0	0	0	0	0	0
1017	Missouri	2239.0	5.1	0	0	0	1.06	1.09
1018	N. Platte	5.5	219.0	9.3	219.0	9.6	169.0	174.0
1019	S. Platte	9.1	37.3	24.1	37.3	24.7	265.0	271.0
1020	Loup	12.3	0	0	0	0	0	0
1021	Platte	45.0	16.8	9.2	14.5	9.4	94.7	97.1
1022	Platte	288.0	30.3	1.8	30.3	1.8	15.4	15.8
1023	Missouri	2353.0	1747.2	20.7	1713.6	21.0	3.8	3.9
1024	Missouri	4372.0	255.2	10.4	255.1	10.5	2.3	2.3
1025	Republican	16.0	0	0	0	0	0	0
1026	Smoky Hill	28.0	28.8	13.9	28.8	13.9	49.6	49.6
1027	Kansas	197.0	26.5	14.7	29.0	16.9	14.5	15.6
1028	Grand	21.0	24.1	10.4	18.6	10.	49.5	51.0
1029	Osage	342.0	56.4	18.0	57.1	18.8	5.3	5.5
1030	Missouri	3494.0	897.1	34.6	940.4	35.3	5.5	5.6

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
Source: Calculated by ANL.

Table C.5. Downstream accounting of water consumption in Region VI by steam electric facilities, using system load factors

Subregion	Stream	7-day/10-year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
1105	Lower Cimarron	6.3	0.3	0	0.03	0	0	0
1106	Arkansas–Keystone	77.4	607.6	10.4	607.6	10.8	13.4	14.0
1109	Lower Canadian	0	14.4	9.3	12.8	8.6	0	0
1110	North Canadian	84.9	219.3	13.2	216.9	12.0	26.5	24.3
1107	Neosho–Verdigris	112.5	42.4	26.8	41.1	26.5	23.8	23.6
1111	Lower Arkansas	1,893.1	934.6	56.6	897.9	57.8	6.1	6.1
1101	White	2,539.7	89.9	8.2	13.4	8.5	0.3	0.3
804	Lower Red–Quachita	438.0	281.8	2.5	257.8	2.0	0.6	0.5
1113	Red–Washita	55.0	2.6	1.7	0	0	3.1	0
1114	Lower Red	1,579.7	413.2	67.9	400.0	61.2	4.4	3.9
808	Louisiana Coastal	61.8	141.7	5.1	137.0	2.2	8.3	3.6
1202	Neches	129.9	184.8	0.8	0	0	0.6	0
1201	Sabine	220.2	612.8	48.3	280.1	45.6	22.3	20.7
1203	Trinity	208.5	484.4	55.9	429.7	39.9	26.8	19.1
1205	Brazos Headwaters	0	16.6	10.7	14.6	9.7	0	0
1206	Middle Brazos	76.6	235.0	67.4	174.2	63.7	102.0	95.8
1207	Lower Brazos	257.8	68.3	39.1	59.0	38.7	45.5	43.5
1204	Galveston Bay–San Jacinto	30.0	32.5	10.7	10.2	6.6	35.7	22.0
1210	Central Texas Coastal	116.1	452.7	26.3	440.3	23.0	22.7	19.8
1208	Colorado Headwaters	0	30.2	6.3	0	0	0	0
1209	Lower Colorado–Bernard Coastal	127.7	499.4	50.0	361.7	48.2	44.1	37.7
1211	Neuces–Southwestern Coastal	32.6	138.9	12.6	137.2	11.8	38.7	36.2
1306	Upper Pecos	5.7	0.1	0.1	0	0	1.8	0
1307	Lower Pecos	2.5	5.0	3.2	4.7	3.1	132.0	124.0
1304	Rio Grande–Amistad	7.9	2.2	1.4	0.8	0.6	59.5	46.8
1308	Rio Grande–Falcon	10.9	0.8	0.5	0.8	0.5	47.7	38.5
1309	Lower Rio Grande	12.9	1.9	1.2	1.1	0.7	49.6	38.0

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
Source: Calculated by ORNL.

Table C.6. Downstream accounting of water consumption in Region VI by steam electric facilities, using 100% load factor

Subregion	Stream	7-day/10-year low flow (Mgd)	Estimated water requirement for steam electric facilities in 1985 (Mgd)				Percentage of 7-day/10-year low flow consumed[a]	
			Base case		NEP			
			Withdrawal	Consumption	Withdrawal	Consumption	Base case	NEP
1105	Lower Cimarron	6.3	0.8	0	0.8	0	0	0
1106	Arkansas–Keystone	77.4	868.2	15.6	868.2	14.9	20.2	19.3
1109	Lower Canadian	0	23.2	15.5	19.7	12.8	999.9	999.9
1110	North Canadian	84.9	490.0	30.4	484.6	26.0	54.1	45.7
1107	Neosho–Verdigris	112.5	67.4	43.2	64.4	41.1	38.4	36.5
1111	Lower Arkansas	1,893.1	1,378.1	86.4	1,288.1	84.0	10.1	9.4
1101	White	2,593.7	209.9	13.7	21.8	13.7	0.5	0.5
804	Lower Red–Quachita	438.0	630.2	6.1	575.9	4.1	1.4	0.9
1113	Red–Washita	55.0	5.9	3.9	0	0	7.1	0
1114	Lower Red	1,579.7	613.2	114.2	583.6	93.1	7.5	5.9
808	Louisiana Coastal	61.8	316.7	11.7	306.0	4.7	18.9	7.6
1202	Neches	129.9	412.9	1.8	0	0	1.4	0
1201	Sabine	220.2	1,322.9	81.5	579.7	71.0	37.8	32.2
1203	Trinity	208.5	1,057.6	112.6	932.9	70.3	54.0	33.7
1205	Brazos Headwaters	0	28.2	18.9	23.7	15.4	999.9	999.9
1206	Middle Brazos	76.6	492.6	119.7	334.8	108.5	180.9	161.7
1207	Lower Brazos	257.8	113.4	61.6	88.5	56.6	77.7	70.0
1204	Galveston Bay–San Jacinto	30.0	74.2	49.2	22.7	14.3	164.0	47.7
1210	Central Texas Coastal	116.1	747.2	51.7	715.6	41.8	44.5	36.0
1208	Colorado Headwaters	0	79.5	15.2	0	0	999.9	999.9
1209	Lower Colorado–Bernard–Coastal	127.7	1,063.7	80.2	756.0	74.1	74.7	58.0
1211	Nueces–Southwestern Coastal	32.6	303.0	24.1	299.1	20.8	73.9	63.8
1306	Upper Pecos	5.7	0.3	0.2	0	0	3.5	0
1307	Lower Pecos	2.5	10.4	7.0	9.8	6.3	288.0	252.0
1304	Rio Grande–Amistad	7.9	4.8	3.2	1.8	1.2	131.6	94.9
1308	Rio Grande–Falcon	10.9	1.7	1.2	1.7	1.1	106.4	78.9
1309	Lower Rio Grande	12.9	4.3	2.9	2.5	1.6	112.4	79.1

[a](Total cumulative upstream consumption by energy facilities ÷ 7-day/10-year low flow) × 100.
Source: Calculated by ORNL.